STEMulating

Design Challenges in Science

Grades 6–8

region4

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Challenges

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STEMulating
Design Challenges in Science

STEM design challenges are not recipes to follow, step-by-step instructions that guide students in creating identical projects, or processes that lead them to the same outcome. STEM is about allowing students to apply their content knowledge, creativity, critical thinking, and other skills as they work to solve a problem and create a solution.

Design challenges will take time, so plan accordingly. Squeezing it in or treating STEM practices as "extra" may communicate that the skills and practices are not valuable. Our attitudes and beliefs are important as teachers; who we are informs who our students become. According to Hoffer, "If we model optimism, confidence, and courage about STEM in our classroom each day, students will absorb those" (2016, p. 3).

It is our hope that the design challenges included in this book will help you teach STEM fluency skills and STEM thinking, that these practices become a natural part of your classroom, and that STEM becomes a way of thinking and planning for you.

Grade 6

Challenge 7: Shielding Satellites

Content Objective

I can explain how spacecraft are designed to withstand extremely high and low temperatures in space.

Language Objective

I can use sentence stems to verbally share ideas with my group.

Key Question

How can we insulate a satellite to protect it from extreme temperatures in low-Earth orbit?

Problem

Objects in space, like satellites, are exposed to extreme temperatures. When satellites in orbit near Earth are exposed to sunlight, the surface temperature of the satellite can reach over 150°C (300°F). When the satellite passes behind the Earth, out of the path of sunlight, the surface temperature can drop to -130°C (-200°F). Insulation and thermal control systems are important features of a satellite because the systems located inside the satellite can stop working if the internal temperature of the satellite gets too high or too low.

Design Challenge

A mobile communications company is planning to launch a series of satellites to create a global communication network. Your team of scientists and aerospace engineers is competing with other teams to design the spacecraft bus—the structural part of the satellite. The spacecraft bus must insulate the satellite so that it is able to maintain a stable internal temperature range when exposed to the extreme temperatures of space. The company has asked each design team to build a prototype small satellite (SmallSat) as a proof of concept.

Teacher Notes

A satellite is any object that orbits a planet or star. It is a misconception to only think of satellites as man-made objects that were launched into orbit around the Earth. The Moon is a natural satellite that orbits Earth. Some artificial (man-made) satellites are large, but small satellites are increasingly common because they are very cost effective. Through research, students may learn that SmallSats are classified by size and mass.

During this challenge, students will apply their knowledge of thermal energy transfer to design the spacecraft bus (structural part of the satellite) that will insulate a small satellite so that it can maintain a relatively stable internal temperature in hot and cold environments. Through research, students may learn that a special material called multilayer insulation (MLI) is frequently used on the outside of satellites to reflect much of the Sun's thermal radiation. Satellites are made with insulating materials and have a thermal control system that helps to maintain the internal temperature. While students do not have access to MLI or an electronic thermal control system, they should have access to common household materials that can be used to reflect light and heat as well as materials that can be used as insulation. Students were introduced to thermal conductors and insulators in grade 4 (TEKS 4(6)(B)).

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Teacher Notes continued

Students should understand that there are three primary methods of heat transfer (TEKS 6(9)(A)). **Conduction** occurs when thermal energy (heat) is transferred though direct contact, such as a pot of water on an electric stove burner. Another type of heat transfer is called **convection** that occurs as a gas or liquid moves when heated. When gases or liquids are heated, the warm particles spread out, become less dense, and rise. The particles cool as they move away from the heat source, becoming denser, and begin to sink. This cycle of moving particles is called a convection current. The third method of heat transfer is **radiation** where heat is transferred by waves. Heat from the Sun is transferred to Earth via radiation. In fact, radiation is the only way heat can travel through space. Radiation occurs on Earth as well. Any time you feel heat without touching the source, such as warming your hands by a fire or sitting in sunshine, you experience radiation.

Students should also understand thermal energy moves in a predictable pattern from warmer to cooler until all of the substances attain the same temperature (TEKS 6(9)(B)). When a satellite is in low-Earth orbit and not protected by Earth's atmosphere, its surface temperature can get high when exposed to heat that radiates from the Sun. Once that heat is transferred from the Sun to the external surface of the satellite, thermal energy may be transferred to the internal parts of the satellite due to conduction. For example, the exterior surface of the International Space Station (ISS) would reach 120°C (250°F) when facing the Sun if thermal controls were not present (NASA, 2001). If the internal parts of the satellite get too hot, they could stop functioning.

Conversely, when the satellite passes behind the Earth or Moon, it is not exposed to radiation from the Sun and the external temperature of the satellite can drop low. As an example, the exterior of the ISS would reach -150°C (-250°F) without thermal controls (NASA, 2001). When satellites are out of direct sunlight, the internal temperature of the satellite may fall as heat is transferred from the warmer interior of the satellite to its colder exterior.

Vocabulary

- conduction
- conductor
- convection
- external housing
- insulate/insulator
- radiation
- satellite
- space travel
- spacecraft bus
- stable
- thermal energy

Career Connections

An **aerospace engineer** designs machines that can fly, including aircraft, spacecraft, satellites, and missiles. Most aerospace engineers work for the aircraft industry or government agencies, such as the National Aeronautics and Space Administration (NASA) or national defense agencies.

A **computer programmer** designs, writes (i.e., codes), and troubleshoots computer programs (also known as software). Computer programmers can work in almost any industry.

A **materials scientist** studies the physical and chemical structure and properties of different materials, such as metals, plastics, glass, ceramics, and textiles. They research ways to improve materials or create new materials. Materials scientists usually work in a laboratory and can find work in many different industries where products are made.

Things to Consider

- Consider limiting materials or incorporating a budget to increase the complexity of this challenge.
- **TEST** and **EVALUATE** will take some time for this challenge. Plan testing procedures in advance based on available testing materials, space, and the number of student teams/prototypes. If time is limited, consider having some teams focus on protecting the satellite from high temperatures while other teams focus on cold temperatures. Pair "hot" and "cold" teams so they may compare research and designs and collaborate on final prototypes. Another option is to have paired teams build similar prototypes and assign a different testing environment to each team. A third option is to conduct low temperature testing and high temperature testing on separate days.

Suggested Materials

For the teacher

- balance or digital scale that can measure at least 1 kg (2.2 pounds)
- container of ice that is large enough to contain prototypes during low temperature testing, such as an ice chest or large sink, and additional ice as needed
- heat lamp(s) or other safe sources of heat
- salt or rock salt (optional)
- second container that is large enough to contain prototypes during high temperature testing, such as an ice chest or large sink (optional), and additional ice as needed
- thermometers or temperature probes (to measure external temperatures in testing areas)
- timers for testing areas

For each team

- access to a balance or digital scale that can measure at least 1 kg (2.2 pounds)
- bubble wrap
- cardboard
- chenille stems
- cotton balls or cotton padding
- craft sticks
- foam trays, plates, bowls, cups, and/or pieces
- foil
- glue
- hot glue guns with glue sticks (optional)
- packing peanuts
- plastic containers, bottles, and/or cups
- plastic wrap
- recycled paper or newspapers
- ruler
- scissors
- string or yarn
- tape
- thermometer or temperature probe (to measure temperature inside prototype)

Advance Preparation

- Place one or more balances or scales in a designated area where teams can measure the mass of their prototypes during **CREATE/TEST/IMPROVE** and **EVALUATE/COMMUNICATE**.

- Prepare one or more low temperature testing areas. Fill a large container, such as a plastic or foam ice chest, a large plastic container, or a large sink, approximately half full with ice. If salt or rock salt is available, add generously to the ice to lower the temperature in the testing area. If possible, keep the testing area covered to reduce melting. Place a thermometer or temperature probe in the ice to record the external temperature of the testing area. (Teams will place a second thermometer or temperature probe inside the prototype to measure the internal temperature.) Place a timer in each testing area.

  Tip: Check the ice level frequently and replace as needed.

- Prepare one or more high temperature testing areas. The maximum testing temperature will depend on the materials available for testing. If possible, use a container similar to the low temperature testing area, such as a plastic or foam ice chest, a large plastic container, or a large sink. Position one or more heat lamps over the testing area to raise the air temperature as much as possible. Place a thermometer or temperature probe in the testing area to measure the external temperature. (Teams will place a second thermometer or temperature probe inside the prototype to measure the internal temperature.) Place a timer in each testing area. Post a sign to remind students of safety guidelines.

  Tip: Turn the lamp(s) on in advance so the testing area is warm before teams begin testing. Keep lamps on continuously during testing.

- If possible, test the hot and cold testing areas in advance. Make adjustments to the testing areas and/or timing as needed.

Suggested Time Frame

- **ASK, IMAGINE, and PLAN:** 1–2 hours; may be broken down over one or more class periods
  - Research **(not more than 60 minutes)**
  - Explore the materials **(about 5 minutes)**
  - Sketch and plan independently **(about 10 minutes)**
  - Reach team consensus on final design **(about 10–15 minutes)**
- **CREATE/TEST/IMPROVE: 30–60 minutes**
- **EVALUATE/COMMUNICATE:**
  - **10–20 minutes** for testing prototypes
  - **3–5 minutes** for each presentation
  - **5–10 minutes** for reflection
  - **5 minutes** to complete rubric

The amount of time needed for this challenge may vary depending on your students' research skills and findings.

Texas Essential Knowledge and Skills (TEKS) for Science Connections

Science Concepts

6(11) Earth and space. The student understands the organization of our solar system and the relationships among the various bodies that comprise it.

(C) The student is expected to describe the history and future of space exploration, including the types of equipment and transportation needed for space travel.

6(9) Force, motion, and energy. The student knows that the Law of Conservation of Energy states that energy can neither be created nor destroyed, it just changes form.

(A) The student is expected to investigate methods of thermal energy transfer, including conduction, convection, and radiation.

(B) The student is expected to verify through investigations that thermal energy moves in a predictable pattern from warmer to cooler until all of the substances attain the same temperature such as an ice cube melting.

Scientific Investigation and Reasoning

6(1) The student for at least 40% of the instructional time, conducts laboratory and field investigations following safety procedures and environmentally appropriate and ethical practices.

(A) The student is expected to demonstrate safe practices during laboratory and field investigations as outlined in Texas Education Agency-approved safety standards.

(B) The student is expected to practice appropriate use and conservation of resources, including disposal, reuse, or recycling of materials.

English Language Proficiency Standards (ELPS)

3(E) Cross-curricular second language acquisition/speaking. The student is expected to share information in cooperative learning interactions.

Teacher Guide

LAUNCH

Present or introduce the problem using an image, article, or video about low-Earth orbit or why space is cold if the Sun is hot.

FACILITATION QUESTIONS:

- What is a satellite?
- What are some uses of satellites?
- What do we mean by low-Earth orbit?
- What conditions exist in low-Earth orbit?
- Why is space cold if the Sun is hot?
- How does heat energy travel through space?

ENGINEERING DESIGN PROCESS (EDP)

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Engineering Design Process

ASK

- Divide the class into teams of 3–4 students.
- Assign each team a place to work.
- Distribute the design challenge card to each team.
- Facilitate the creation of a "Know/Need to Know" T-chart and ensure students understand the challenge

FACILITATION QUESTIONS:

- What do we know about satellites? What do we need to know?
- What do we know about low-Earth orbit? What do we need to know?
- What do we know about heat transfer? What do we need to know?
- What are the criteria?
- What are the constraints?
- What materials are available for this challenge?
- How will the prototype be tested?
- What are some careers that are related to this challenge?

Teacher Guide

Engineering Design Process

IMAGINE

- Provide research materials (access to the Internet or experts, artifacts, books, science notebooks, and magazines).
- When necessary, define vocabulary and model techniques for research and notetaking.
- Observe teams to assess and provide feedback on their collaboration, creativity, critical thinking, communication, and resiliency skills.
- Allow students to observe and explore the available materials.
- Show students the testing area and explain the testing process.

Note: *Do not give materials to teams at this time.*

SUGGESTED RESEARCH TOPICS:

- spacecraft bus
- satellite temperature control or thermal control
- materials used to make satellites
- conduction, convection, and radiation
- reducing heat transfer (insulation)
- conditions in low-Earth orbit

FACILITATION QUESTIONS:

- What type(s) of heat transfer affect a satellite in low-Earth orbit?
- What are some methods and/or materials that reduce heat transfer?
- How are other satellites protected from extreme temperatures?

Engineering Design Process

PLAN Independent Planning

- After they have finished their research, instruct students to create a sketch of their individual ideas. Remind students to include details such as labels, measurements, and explanations of how each part functions.
- Instruct students to think about one of the sentence stems below and complete the sentence.
  - I think my team could solve this problem by . . .
  - My idea for solving this problem . . .
  - Based on my research and understanding, I think we should . . .

FACILITATION QUESTIONS:

- What did you learn from your research?
- How have others solved this problem?
- What are your ideas to solve this problem?
- Which of the materials would be best for ______________________________?

PLAN Team Planning

- Facilitate consensus building and planning, encourage engagement, and support detailed sketching. Remind students to use the sentence stems provided during independent planning.
- Provide a clean sheet of paper for each team to record their final plan.
- Provide feedback to student teams on their final design and plan.
- Assist teams in managing roles and help team members understand their responsibilities within the challenge.
- Allow Materials Managers to collect the materials for their team.
- Observe teams to assess their collaboration, creativity, critical thinking, communication, resiliency, and application of content knowledge.

SUGGESTED ROLES:

- Project Manager
- Quality Control Manager
- Construction Manager
- Materials Manager

FACILITATION QUESTIONS:

- What did you learn from your research?
- Which idea or combination of ideas will the team use?
- Which materials would be best for your design?
- How will you measure the temperature inside the prototype?
- Where might heat move in or out of your prototype? Is there something you can do to prevent this heat transfer?
- What materials do you need?

SENTENCE STEMS:

- Our plan for solving this problem is . . .
- We will need the following materials . . .
- The steps we will take are . . .
- Our role assignments are . . .

Teacher Guide

Engineering Design Process

CREATE/TEST/IMPROVE

- Manage materials and ensure students follow safety guidelines.
- Allow teams to work together to create their prototypes.
- Remember not to take over the design process.
- Observe teams to assess and provide feedback on their collaboration, creativity, critical thinking, communication, resiliency, and application of content knowledge.
- Review concepts that may help students improve their designs.
- *Review the test process. Encourage teams to test and improve prototypes. Remind teams of any testing constraints during* **CREATE/TEST/IMPROVE**.
- Encourage students to plan their presentations using the following sentence stems.
  - We will showcase our prototype by . . .
  - Our prototype works by/because . . .
  - The materials we used were . . .
  - We chose these materials because . . .
  - First we tried _____________, then we _____________.

Engineering Design Process

EVALUATE/COMMUNICATE

- Facilitate the presentation and testing process. Ensure each group uses the same testing process.
- Accept and expect failure; failure is an opportunity to learn and improve.
- Facilitate student reflection on their design process. Ask questions to help students think critically about the successes and failures of their designs.
- Allow time for students to ask questions of each other, reflect, note, and communicate their observations.
- Facilitate the use of the rubric.

TEST PROCESS: Low Temperature Test

1. If not already present, place a thermometer or temperature probe in the ice.
2. Place a thermometer or temperature probe inside the prototype.
3. Place the prototype in the ice. Ice should reach at least halfway up the sides of the prototype. If more than one team is testing at the same time, wait until all prototypes are positioned before moving to the next step.
4. Set a timer for 5 minutes and press start.
5. When the time is up, remove the prototype from the ice. Check and record the internal temperature as directed by the teacher.
6. Check and record the external temperature (temperature of the ice) as directed by the teacher.
7. Reset the materials for the next team. Add ice and remove excess water as needed.

TEST PROCESS: High Temperature Test

1. The heat source should already be on. If not, turn on the heat source and wait 5–10 minutes to begin testing.
2. If not already present, place a thermometer or temperature probe in the heated testing area.
3. Place a thermometer or temperature probe inside the prototype.
4. Place the prototype in the heated testing area. If more than one team is testing at the same time, wait until all prototypes are positioned before moving to the next step.
5. Set a timer for 5 minutes and press start.
6. When the time is up, remove the prototype from the test area. Check and record the internal temperature as directed by the teacher.
7. Check and record the external temperature (temperature of the test area) as directed by the teacher.
8. Reset the materials for the next team. Leave the heat source on unless instructed to turn it off by your teacher.

Safety Note: *Use caution when working around heat lamps. Do not touch the lamp or the bulb.*

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Teacher Guide

Engineering Design Process

EVALUATE/COMMUNICATE continued

FACILITATION QUESTIONS:

- What materials did your team use? Why did you choose those materials?
- What is the mass of your final prototype?
- What are the dimensions of your final prototype?
- How well did your design meet the criteria for cold temperatures?
- How well did your design meet the criteria for warm temperatures?
- Where do you think thermal energy moved in or out of the prototype?
- What could be improved or done differently?

REFLECT:

- Facilitate student reflection on the science concepts applied to complete the design challenge.
- Ask questions about related science and STEM careers to help students make career connections.

REFLECTION QUESTIONS:

- What did you learn about satellites?
- What did you learn about low-Earth orbit?
- How can we insulate a satellite to protect it from extreme temperatures in low-Earth orbit?
- What do you know about the job of an aerospace engineer? A materials scientist? A computer programmer?
- What questions do you still have?

EXTENSION ACTIVITIES:

- If students have access to and experience working with single-board computers, such as Arduino® or Raspberry Pi®, teams can be challenged to create their own temperature sensor that can be placed inside the prototype during testing.
- If students have access to a 3-D printer, challenge teams to design and print a CubeSat frame.
- Have students research the different types of satellites and how groups of small satellites can work together to replace single, larger satellites

DESIGN Challenge Card

Challenge 7: Shielding Satellites

Key Question

How can we insulate a satellite to protect it from extreme temperatures in low-Earth orbit?

Problem

Objects in space, including satellites, are exposed to extreme temperatures. When satellites in orbit near Earth are exposed to sunlight, the surface temperature of the satellite can reach over 150°C (300°F). When the satellite passes behind the Earth, out of the path of sunlight, the surface temperature can drop to -130°C (-200°F). Insulation and thermal control systems are important features of a satellite because the systems located inside the satellite can stop working if the internal temperature of the satellite gets too high or too low.

Design Challenge

A mobile communications company is planning to launch a series of satellites to create a global communication network. Your team of scientists and aerospace engineers is competing with other teams to design the spacecraft bus—the structural part of the satellite. The spacecraft bus must insulate the satellite so that it is able to maintain a stable internal temperature range when exposed to the extreme temperatures of space. The company has asked each design team to build a prototype small satellite (SmallSat) as a proof of concept.

Criteria

- ❑ The prototype must contain space for a thermometer or temperature probe to be placed inside during testing
- ❑ The internal temperature of a successful prototype will not drop more than 5°C during the low temperature test.
- ❑ The internal temperature of a successful prototype will not rise more than 5°C during the high temperature test.
- ❑ The presentation should describe—
  - the materials and how they were selected;
  - how radiation, convection, and conduction were considered in the prototype design; and
  - the results of the low temperature and high temperature tests.

Constraints

- ❑ Teams may choose only from the materials provided.
- ❑ The size of the prototype must be no larger than 10 cm × 10 cm × 10 cm.
- ❑ The mass of the prototype must not be greater than 1 kg.
- ❑ You will have 45 minutes to create your prototype.

Safety Note:

- *Use caution if working with a hot glue gun.*
- *Use caution when working around heat lamps. Do not touch the lamp or the bulb.*

Challenge 7: Shielding Satellites

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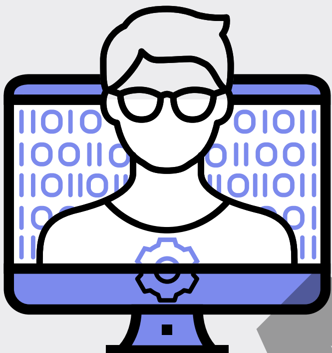

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